CHAPTER THREE

Steam Engineering

> Pushing the accuracy of the measurements "as far as possible with the apparatus available"
>
> —Callendar and Egerton

Guy Stewart Callendar became one of Britain's premier steam engineers and thermodynamicists, having learned his trade as a research assistant under his father's tutelage at Imperial College (see Chapter 1). His introduction to the world technical stage came in July 1929 when he participated in the First International Steam Table Conference held in London under the sponsorship of the British Electrical and Allied Industries Research Association (BEAIRA).[1] The conference convened engineers and physicists from Great Britain, Germany, the United States, and Czechoslovakia interested in the determination of the properties of steam over a wide range of temperatures and pressures. On Monday, July 8, Dr. Samuel Adamson, President of Institution of Mechanical Engineers (IMechE) opened the conference in the Council Chamber of the Institution. The first two and a half days were dedicated to presentations, discussions, and critiques. For the remainder of the week, delegates attempted to create standardized units and procedures, "so as to avoid in the future the discrepancies which up to the present exist between the Steam Tables used most generally by the different engineering countries of the world."[2] The conference adopted, as the recommended unit for the measurement of the total heat of steam, the International Calorie, defined as follows: "One international kilowatt-hour equals 860 international

kilocalories."[3] This unit was independent of secondary properties derived from the behavior of water, local variations in the acceleration of gravity, and the value of Joule's mechanical equivalent of heat. Yet, since important theoretical questions and national engineering practices remained at issue, the delegates agreed to meet again for a second conference in 1930.

Following his father's death in 1930, G. S. Callendar rededicated himself to steam engineering. He lectured on the results of his father's research at Manchester and Cardiff[4] and the BEAIRA Turbine Committee continued funding his steam research, increasing his salary from £300 to £450.[5] Guy Callendar's work on steam was both a labor of love—an expression of filial piety for his father—and a testimony to the rigorous and practical training he had received from him.

Callendar's colleague in these efforts was the celebrated physical chemist Alfred Egerton, then at Oxford University. Funded by BEAIRA, and pursuing the agenda established by the International Steam Table Conference, Callendar and Egerton led the British effort to define international units, coordinate investigations on steam, and reduce errors and inconsistencies in its thermodynamic properties as measured by different techniques.

Alfred Egerton

Alfred Charles Glyn Egerton (1886–1959) was known from childhood to his close friends and associates as "Jack." He was educated at Eton College, where he established their scientific society, and at University College London, where he studied chemical thermodynamics with Sir William Ramsey, graduating in 1908 with first-class honors. Egerton continued his chemical studies at Nancy University (1909) and Berlin University (1913). He worked as a chemistry instructor at the Royal Military Academy, Woolwich, from 1909 to 1913. During World War I he served as an assistant in the Department of Explosives Supply, Ministry of Munitions. Here he would have likely crossed paths with Professor H. L. Callendar. In 1912 he married the Honorable Ruth Cripps, who shared his lifelong passion for travel and painting, especially watercolors. The childless couple adopted Jack's nephew Francis, whose father had been killed in action in France.

After the war, Egerton matriculated at Oxford University, where he worked as a lecturer, earning his master's degree in chemistry in 1921 and gaining promotion to reader in thermodynamics in 1923. He was elected a Fellow of

the Royal Society in 1926, serving on their council from 1931 to 1933, about the time of his first collaboration with Guy Callendar. Egerton served as professor of chemical technology at Imperial College from 1936 to 1952 and as Physical Secretary of the Royal Society from 1938 to 1948. During World War II he was a member of the War Cabinet Scientific Advisory Committee and chaired the Fuel and Propulsion Committee of the Admiralty. Here Egerton would have had oversight of the FIDO project (see Chapter 4) that involved Guy Callendar.

Egerton was knighted in 1943 and was awarded the Rumford medal of the Royal Society in 1946. After the war he served on a number of scientific advisory panels, including as the director of Salter's Institute of Industrial Chemistry and as an official scientific liaison to the United States and India. He was founding editor of the journal *Fuel* and, in addition to many other honors, received the first Egerton medal from the Combustion Institute in 1958. He died suddenly, on September 7, 1959, while on a painting holiday in France.[6]

Alfred Egerton dedicated his entire life to his scientific pursuits. He was quiet and spoke little, but kept detailed daily diaries. He enjoyed long walks and skiing. "Above all he had an immensely humorous and tolerant way of seeing things."[7] Egerton was introduced to Callendar both personally and professionally when he visited Imperial College on February 20, 1930, to inspect his steam apparatus. The meeting was facilitated by Henry Lewis Guy of BEAIRA, who hinted at the possibility of funding, and Sir Henry Tizard, Rector of Imperial College, who recommended the collaboration.[8] Egerton's initial impression was that Callendar was "lacking fire." However, after witnessing an experiment he was convinced of Callendar's technical ability and was "very satisfied with the temperature measurements and with the running of the plant." He thought the experiments were working out "satisfactorily and interestingly."[9] If Guy Callendar was influenced by his father before 1930, it is clear that his mentor became Alfred Egerton after 1930. Theirs was a lifelong collaboration.

The Callendar–Egerton Collaboration

The years between 1930 and 1933 were busy ones for Egerton and Callendar. They conducted a series of experiments on the steam apparatus at Imperial College, compared their results with those of their American colleagues,

prepared for the Second International Steam Table Conference in Berlin, and published a paper in 1933.

The experimental setup of H. L. Callendar was modified to provide a continuous flow of steam at high pressures and temperatures, allowing them to make "dynamical" measurements of saturation pressures (Figure 3.1). In the experimental apparatus, pure distilled water, stored in two stoneware jars, was pumped into a boiler for removal of traces of air, from which it passed into a glass storage vessel. A triple-throw hydraulic pump drew it from the vessel and forced a steady flow into the electric boiler through 19 corrosion-resistant tubes made of monel metal (an alloy of nickel, copper, and other metals). The mixture of water and steam, at pressures as high as 5000 psi, passed through the coil of the gas-heated superheater before entering the high pressure pocket. It was here that the temperature of the steam was measured with the leads of a platinum resistance thermometer, and the pressure of the steam was measured by a large differential dead-weight gauge. After passing through the throttle tube, the steam was expanded and condensed, providing a measure of its saturation.[10]

After pushing the accuracy of the measurements "as far as possible with the apparatus available," the duo found "no appreciable differences" between their technique and the American technique of making "statical" measure-

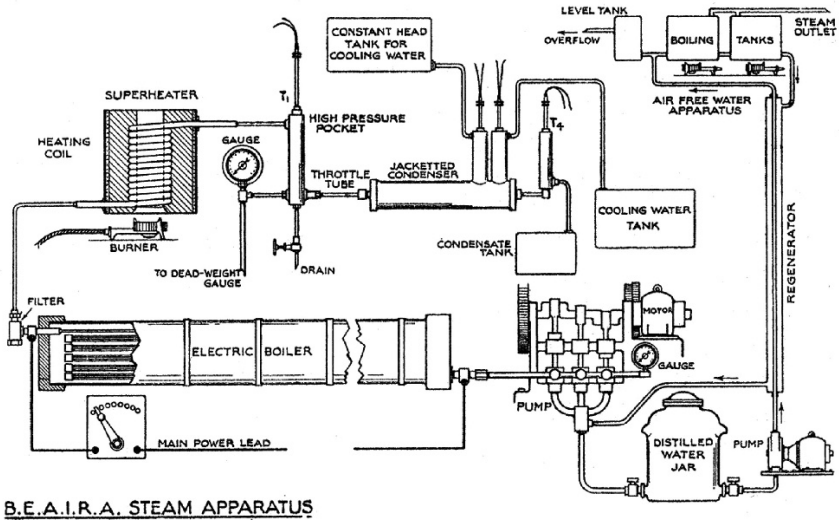

Fig. 3.1. Schematic of experimental apparatus used by Callendar and Egerton for measuring the dynamical saturation pressure of steam.

ments of steam, pioneered by Frederick G. Keyes.[11] Callendar and Egerton brought their early results to the Second International Steam Table Conference, held in Berlin June 23–26, 1930.[12] Their trip was supported by BEAIRA. Although the Conference came to no consensus, and the British and American delegations disagreed on both theoretical and practical issues, all agreed that further meetings were desirable.[13]

The Third International Steam Table Conference

In 1934 Guy Stewart Callendar attended the third International Steam Table Conference held in Washington, Boston, and New York. Sponsored by the American Society of Mechanical Engineers (ASME), the conference was an international attempt to standardize the actual and theoretical behavior of steam at high temperatures and pressures. Not only was it the final steam conference in the series, it was the best documented, and arguably, the one to which Guy made the most significant contribution. Guy's love letters to Phyllis (the only ones we have), Alfred and Lady Egerton's personal journals, the conference program, and a published meeting report provide a relatively complete account of the meeting and a window into Guy's professional and personal life.[14]

Callendar's letters home are private, thoughtful, and loving (see Appendix B). While he mentioned the steam conference, he was more concerned with describing to Phyllis luxuries of the trip such as extravagant meals, opportunities to play tennis, cinematic entertainment, and personal reflections on the United States. He also frequently commented about the weather, which is no surprise due to Callendar's growing interest in meteorology.

Egerton's journal was written retrospectively and includes impressions of New York and Boston, race relations in the United States, and a visit with Henry Ford.[15] Lady Egerton's journal contains considerably more detail, including their departure by train from London with Callendar, who she referred to as "Jack's assistant and colleague on the work," and their departure on September 8 from Liverpool on the White Star Liner *Britannic*, "a very comfortable 'cabin class' oil motor ship with every luxury." Also traveling with them to the conference were H. L. Guy, "a great engineer from Manchester and his wife," and Mr. Robinson, from the BEAIRA, and his wife. BEAIRA allocated £250 for the Egerton's expenses, and probably slightly less for Callendar.

Journey across the Atlantic

The *Britannic* was a new diesel-powered ship of the White Star Line, with a low profile, sleek superstructure, and Art Deco design.[16] The captain must have been especially proud to show off the new state-of-the-art engine room to the prestigious group of engineers on the voyage. Callendar wrote to his wife, "Went over the engines of this ship with Mr. Guy yesterday, they are I.c. [internal combustion] that is like those in a motorcar. The engine room is like 500 large lorry engines all going together in a tin shed, it is no place for ladies."[17] Since diesel power left the engine room very cool, it was equipped with heaters. This was quite different from the sweltering environment of coal-fired, steam-powered engines. Callendar must have been impressed that the *Britannic*'s fuel consumption was only 40 tons per day, down 50 percent compared to steam.[18] According to Callendar, deck tennis was the most amusing game on board the ship, "it is just like Badminton except that you catch a ring instead of hitting a shuttle."[19]

As the voyagers neared the U.S. coast in the early morning of Sunday, September 16, a thick marine fog greeted the travelers as the *Britannic* docked at the Cunard Pier in East Boston.[20] They passed emigration and customs in two hours, were met by members of the American delegation, and lunched at

Fig. 3.2. Guy Callendar, 1934, "in Boston standing amongst cars with pipe and hat."

the Harvard Faculty Club (Ruth called it the "Fraternity House") hosted by Harvard professor Lionel Marks. The group toured the Harvard Museum of Natural History, motored to Lexington (Figure 3.2),[21] "where the primitive men sprang up from the farms and beat the British!", and rushed back to Boston for a bite at the Union Oyster House ("America's oldest restaurant").[22] Guy noted that Boston had nice residential districts and a magnificent harbor with small islands in it. That evening, after a very full day, Callendar, Egerton, and the other steam engineers caught an overnight train ("rather uncomfortable sleeper with common wash place") to Washington ("a fine city with solid looking white buildings").[23] Ruth remained behind in Boston at the Parker House.

Session One: Washington

After a long night of travel and breakfast on the train, the delegates arrived in Washington, D.C. and were escorted to the Broadmoor Hotel—but not to spend the night. At 10:00 AM the delegates congregated at the National Bureau of Standards (NBS) and heard welcoming addresses from its director Dr. Lyman J. Briggs and other dignitaries. After an exchange of reports and assignment of the working subcommittee (of which GSC was a part), the delegates visited the Heat and Power Laboratory at NBS and were briefed on the construction and operation of apparatus used in research on the thermal properties of steam. The delegates took a group photo (Figure 3.3),[24] lunched at the NBS, toured local points of interest, and concluded a long day with dinner at the Broadmoor Hotel.

At 9:00 P.M. the delegates reboarded the Federal Express en route to Boston for the second session of the conference—another night in transit.

Session Two: Boston

Arriving in Back Bay Station, Boston at 7:45 A.M. on Tuesday, September 18, Callendar, Egerton, and the other delegates were transported to MIT where they took breakfast at Walker Memorial and assembled in Eastman Laboratory, which Ruth called "an enormous kind of National Physical Laboratory." Harvard Professor Harvey N. Davis presided and Institute President Karl T. Compton offered formal greetings.[25] Then the delegates inspected apparatus for investigating the thermodynamic scale of temperature. Afternoon

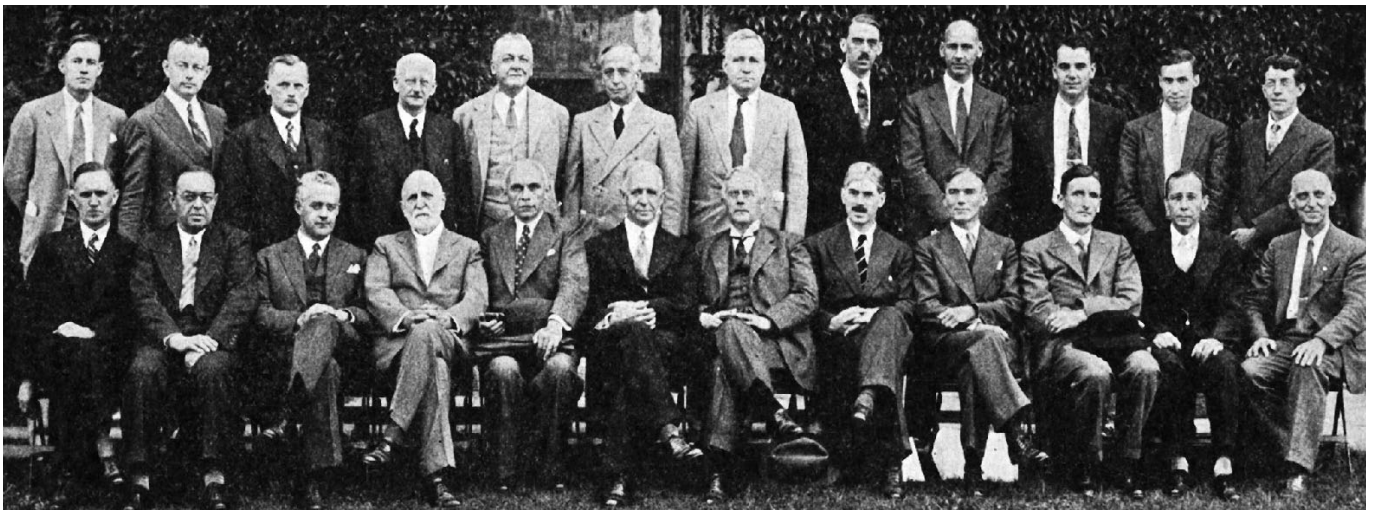

Fig. 3.3. Participants in the Third International Steam Table Conference at the National Bureau of Standards, 1934. *Left to right, standing*: C. G. Worthington, F. Michel, E. Schmidt, G. A. Orrok, F. M. Feiker, C. B. Le Page, E. F. Mueller, E. J. M. Honigmann, J. H. Keenan, D. C. Ginnings, E. F. Fiock, H. F. Stimson. *Seated*: H. Hausen, W. Koch, H. L. Guy, A. Dow, F. Henning, L. J. Briggs, I. V. Robinson, A. C. G. Egerton, F. G. Keyes, G. S. Callendar, N. S. Osborne, H. C. Dickenson.

sessions were followed by tours around MIT and Harvard and tea in the Eastman Lab.

At 5:00 P.M. the party departed for New York City aboard the Hamburg-American Liner *New York*.[26] En route, the delegates enjoyed the sights along the New England coast and dined on board. The evening concluded with informal discussions, music, dancing, and another, more comfortable night's rest—but still in transit.

Session Three: New York

On Wednesday morning, September 19, the delegates arrived in New York City. Ruth had "never seen a more wonderful sight" as she "watched the great sky line of the sky scrapers coming nearer and nearer as we came up the river. The Empire [State] Building, the Chrysler Building, and Radio City stood out. All these looked like huge cathedral towers in pinkish white and pale blue shadows with a soft haze and gorgeous sun."[27] As the delegates settled in to the "old fashioned" Astor Hotel in Times Square, Ruth recounts meeting a number of participants including the German delegation: "Dr. Schmidt (rather a Nazi), Prof. Henning, Prof. Dreuser and nice fat Dr. Koch of Munich. They had left their wives who mostly seemed obeying Hitler's commands to increase the *vaterland*. Also a nice Austrian Dr. 'Honymann.'"[28]

The third session of the conference began at 10:30 A.M. at the headquarters of ASME in the Engineering Societies Building on 39th Street. Dr. Davis again presided and Dr. Calvin W. Rice, Secretary of ASME, greeted the delegates. That evening's formal conference dinner was held at the Hotel Astor, with Alex Dow of Detroit Edison presiding and after dinner remarks by Col. Paul Doty, President of ASME. Guy wrote that the dinner lasted from 7:00 to 11:30 P.M., and the "speeches nearly sent everyone to sleep."[29]

The remainder of the week was dedicated to the work of the subcommittee formed in Washington, "considering contributions of new experimental evidence and preparing a report for the revision and extension of the current international skeleton table."[30] Final presentations were scheduled for Saturday morning, September 22.[31] Although Callendar and Egerton had to fight for their experimental figures on total heat, they concluded in the end that the final results would be very near the agreed-upon figures. In the end the conference was voted a "tremendous success by all concerned," although, as in earlier conferences, only limited progress had been made

toward a complete set of data upon which to construct steam tables, and differences in theory, techniques, and equipment prevented the publication of an international set of steam tables.[32]

Guy's experience in New York was not limited to the conference. His evenings were free and filled with various forms of entertainment. He visited the top of the Empire State Building and "looked down on all the lights of New York." He dined with the other delegates at Hotel Astor, hosted by the ASME, and enjoyed another meal at the Waldorf-Astoria, a "new, and very super hotel" with appealing "chromium plate and polished wood interiors." Their party also dined at the New York Society of Arts and enjoyed several sightseeing expeditions. After the commotion of the conference died down, however, homesickness set in:

> Now that all the rush and work of the conference is over I feel frightfully homesick, and long to be back at our quiet little home where I really belong. Once the boat starts moving I shall be all right. I see the *Britannic* started back this morning, I wish I was on her. Many people would think I must be mad to wish to quit living like a lord, free of charge, in the center of New York, but I want to get home to you and the twins. The air here is like warm thick soup, there is no movement, and it tastes & smells *very* secondhand. I have a huge fan in my room, but the air in the streets (canyons) is awful. I long for the glorious fresh breezes of Worthing.[33]

Guy spent the balance of his free time in and around New York City. He played tennis in Hoboken, New Jersey, with Professor J. H. Keenan[34] of the Stevens Institute of Technology and his friends, and was shocked to see students playing tennis with only "the shortest of shorts on, and no shirt which we should think hardly decent as there are plenty of girls about." He had hoped to travel to Philadelphia midweek to meet the Egertons, but these plans were interrupted when it was reported that the *Laconia*, the ship he planned to take home on Friday, had collided with a cargo vessel in the fog and would be out for repairs.[35] Instead Callendar sailed for home on the Cunard–White Star *Mauretania* on Wednesday, September 26, and arrived in Southampton on Tuesday, October 2.[36] It is safe to say that Callendar was happy to be reunited with Phyllis and the twins, but he also enjoyed and profited from his experiences at the Third International Steam Table

Conference, where he again rubbed shoulders and exchanged ideas with the technical elite of America and the world.

Steam Research to 1941

Callendar and Egerton's collaboration continued long beyond the steam conferences. Guy continued steam research with Edgerton for the turbine manufacturers from 1930 to 1941. Under pressure to maintain the "prestige of this country" and compete with the Americans in the race to compile steam tables, Callendar and Egerton published *The 1939 Callendar Steam Tables*, with subsequent editions, along with heat–entropy diagrams, appearing in 1944, 1949, and 1957.[37]

In 1939 there was some discussion of holding a fourth International Steam Table Conference in Prague in late June. Yet reaching international agreement on steam was an elusive goal, for as Egerton wrote, "I do not think the Conference could possibly come to agreement on [the editing of a single International Steam Table] at present . . . [since it] would need to be thermodynamically consistent throughout and to lie within the agreed errors of the observed results."[38] Regardless, the conference was never held due to the threatening political situation in Czechoslovakia.

By September 1939, with the outbreak of war in Europe, Egerton and Callendar had to make emergency contingency plans for the fate of their steam apparatus at Imperial College. Options included (a) continuing the work on site, (b) leaving the apparatus intact during the war, and (c) transferring the apparatus to a "neutral" zone. Although concerns were raised about the safety of London, the priority of steam research, the cost of moving the apparatus, and possible personnel shortages, we know that the apparatus remained intact through 1941. Early in the war, Callendar busied himself with compiling a concise final report from all the earlier work that had been completed.[39] He continued his steam research, attending BEAIRA subcommittee meetings and reporting on his attempts to measure the total heat of steam at higher temperatures and pressures.[40] However, at this point it was clear to all parties involved that the work of Egerton and Callendar on steam research was coming to an end.

The steam work came to a formal close at a BEAIRA Turbine Research Committee meeting on July 11, 1941. Callendar, present by invitation,

commented on the investigations and asked that the apparatus be kept set up at Imperial College in case further testing was needed. It was noted that Professor Egerton was preparing a final report for publication, and the Committee recorded its appreciation of the work done by Egerton and Callendar.[41]

"What is to become of Mr. Callendar?"

On August 5, 1940, with the Battle of Britain raging, H. L. Guy of Metropolitan Vickers wrote to Dr. E. B. Wedmore, the director and secretary of BEAIRA, about the steam table work nearing completion and the question of "What is to become of Mr. Callendar?" Since Callendar had worked on the steam tables full time for BEAIRA, "ever since he was put on to it at the suggestion of his father," and was considered to be a "very competent experimentalist," Mr. Guy wondered if Callendar could be incorporated into the staff of the BEAIRA Laboratories when his steam work ended.[42] This letter launched a series of consultations and inquiries aimed at finding Callendar a job. Wedmore responded that he too had been "a little troubled as to Mr. Callendar's future," and welcomed Mr. Guy's cooperation. However, he was not very hopeful that Callendar would fit into the work being done at the BEAIRA Laboratory, which was "rather highly specialized" and focused on electrical surge phenomena, radio interference, and the properties of dielectrics. Wedmore thought that Callendar might find a more suitable position in industry or perhaps with the National Physical Laboratory and suggested they have a "frank conversation" with him about his future in which he would "no doubt discuss what he must already have on his own mind."[43] Egerton's correspondence has the annotation "saw Callendar" and includes a note about a possible grant for investigating the thermal properties of hydrocarbons that could provide £500 per year.[44] H. L. Guy was of the opinion that "we should do our best for Callendar," and suggested to Wedmore that Sir Henry Tizard be involved in the discussions.[45]

Egerton was well positioned to assist in Callender's job search. He was chairman of Chemical Technology at Imperial College and Physical Secretary of the Royal Society. In addition to steam, he conducted research on fuels and combustion. During the war, he served as a member (one of only six) of the War Cabinet Scientific Advisory Committee and chairman of the Fuel and Propulsion Committee of the Admiralty.[46] Callendar's résumé of 1940 was in Egerton's possession and is reproduced in Figure 3.4 below.[47]

MR G. S. CALLENDAR

Born 1898. Educated at St. Paul's School, and City and Guilds Engineering College.

During the last war assisted in testing a variety of generating sets for X-ray apparatus, and aircraft engines at Farnborough. Later joined R.N.V.R. as hydrophones officer and had experience with electrical apparatus used for sound ranging.

Assisted Father, the late Professor H. L. Callendar, in numerous researches mainly of an electrical or thermal nature, including his tests on turbines at various power stations.

In collaboration with Father and Professor Egerton designed and operated the E.R.A. steam research apparatus at South Kensington. In this connection have had considerable experience in making out reports and tables dealing with the researches. Have published a paper on electrical thermometry in the Philosophical Transactions of the Physical Society.

Is a Fellow of the Royal Meteorological Society, who has published papers by him dealing with radiation from gases in the atmosphere.

At the invitation of the Air Ministry wrote an article on the past history of the atmosphere, which they published in full in the Meteorological Magazine.

Have knowledge of the use and testing of fuel: in this connection have been invited to attend the visitors day at H.M. Fuel Research Station.

In general his qualification is over 20 years continuous experience in precision measurements, and especially in detecting small errors and designing apparatus to overcome them.

References to papers

The numerous reports on various aspects of the steam research, which have been issued by the E.R.A. (Refs. J/T and JCT) are of course familiar to you.

Besides the above the principal papers under his name are as follow:

"On the vapour pressure of water from 150° to the Critical point." (With Prof. Egerton) Phil. Trans. Roy. Soc. 1931.

"On the reduction of Platinum Resistance thermometers to the International Temperature scale." Phil. Mag. May 14. 1932.

"On the influence of Carbon Dioxide on Earth temperatures." Q.J. Roy. Met. Soc. 64. 1938.

"The atmosphere through the ages." Met. Mag. March. 1939.

"On the variations of Carbon Dioxide in the atmosphere." Quart. J. Roy. Met. Soc. October. 1940.

November 8th 1940.

Fig. 3.4. Callendar's résumé, 1940.

Of course, the technical demands of World War II ensured that G. S. Callendar would remain fully employed (see Chapter 4).

A Hiatus of Nineteen Years

Publication of the Callendar-Egerton steam research results was not completed until 1960. Soon after the end of BEAIRA sponsorship in 1941, Wedmore wrote to Egerton asking about the status of his final report. Egerton replied, "the trouble is that it requires freedom of mind for a few clear days and that I have not got, as soon as I get free something immediately connected with the war crops up which has to be attended to. . . . I am afraid it cannot be what I hoped it might be, for I wanted to get suitable equations that would express the results and the whole work together, but that must wait till after this war."[48]

Publication of the steam research conducted by Callendar and Egerton was in fact postponed many years beyond the war and didn't occur until 1960 in the form of Egerton's final posthumous publication, together with Callendar, in the *Philosophical Transactions of the Royal Society*.[49] In a letter to the Royal Society early in 1959, Egerton explained,"The Total Heat study was ten years of work (1930–1940), but I never had time to get it in form for publication until last summer! There is renewed interest in the subject, particularly in America and Russia, and so I felt it my duty to make the effort to condense the voluminous reports which we had sent during the progress of the work to the Electrical Research Association, and to provide a paper which would be useful to those now working in the field. . . . I hope that the publication will be agreed, in spite of the belated writing up of the work."[50] His diary for December 15, 1958, also notes that "Callendar has written approving the steam paper."[51]